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COSMIC-RAY ANTIPROTONS FROM NEUTRALINO ANNIHILATION IN THE HALO

Fiorenza Donato

Dipartimento di Fisica Teorica dell'Università di Torino and INFN, Italy

We report the main results of a paper where recent data of low-energy cosmic-ray \bar{p} spectrum have been analyzed in terms of newly calculated fluxes for secondary antiprotons and for a possible contribution of an exotic signal due to neutralino annihilation in the galactic halo. We also present the results of a paper in which we have proved that a sizeable fraction of the supersymmetric neutralino configurations, singled out by the DAMA/NaI data on a possible annual modulation effect in WIMP direct search, may provide detectable cosmic-ray antiproton signals.

1 Introduction

Relic neutralinos, if present in the halo of our galaxy as a component of dark matter, would annihilate, and then produce indirect signals of various kinds. Among them, cosmic-ray antiprotons are certainly one of the most interesting^{1,2} and may be detected by means of balloons or of space missions. To discriminate this potential source of primary \bar{p} 's from the secondary ones, we can use the different features of their low-energy spectra ($T_{\bar{p}} \lesssim 1$ GeV, $T_{\bar{p}}$ being the antiproton kinetic-energy). In this energy regime the interstellar (IS) secondary \bar{p} spectrum is expected to drop off very markedly because of kinematical reasons, while primary antiprotons would show a milder fall off. This discrimination power is somewhat hindered by some effects we try to clarify in the following sections.

2 Cosmic-ray proton spectrum

We have first to fix the primary IS cosmic-ray proton spectrum, since we need it for the evaluation of the secondary \bar{p} 's. The IS cosmic-ray proton spectrum is derived by assuming for it appropriate parametrizations and by fitting their corresponding solar-modulated expressions to the TOA (top of the atmosphere) experimental fluxes. In the present paper we use the two most recent high-statistics measurements of the TOA proton spectrum reported by the IMAX Collaboration³ and by the CAPRICE Collaboration⁴. We fitted these spectra using two different parametrizations: one depending on the total

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proton energy, $E_p = T_p + m_p$, and the other on the momentum, p (equivalent to rigidity for protons). The detailed results of our best fits to the proton data can be found in Table I of Ref.², in terms of the normalization coefficient, the spectral index and the solar-modulation parameter Δ . We find that even using both the parametric forms for the IS proton spectrum, the data of the two experiments do not lead to a set of central values for the parameters mutually compatible within their uncertainties. In Fig.1 we report the median proton flux, with its uncertainty band, as obtained from the fits to the data of the two experiments.

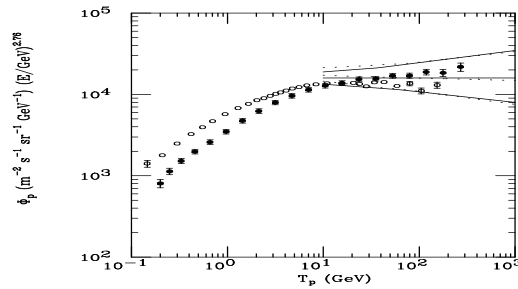


Figure 1: TOA spectra of IMAX (full circles) and of CAPRICE (open circles). The solid (dotted) lines denote the median, minimal and maximal IS proton fluxes obtained with parametrization in energy (rigidity).

3 Secondaries \bar{p} 's fluxes

Cosmic ray protons interact with hydrogen atoms at rest, lying in the gaseous HI and HII clouds of the galactic ridge, and may produce \bar{p} 's. This conventional spallation process is actually a background to an hypothetical supersymmetric antiproton signal. The propagation of cosmic rays inside the Galaxy has been considered in the framework of a two-zone diffusion model^{5,2}. We have included energy losses in the diffusion equation, which tend to shift the antiproton spectrum towards lower energies with the effect of replenishing the low-energy tail. The steps of the method we followed to calculate secondary \bar{p} 's production and diffusion are fully described in Ref.²

4 \bar{p} 's from neutralino annihilation

The differential rate per unit volume and unit time for the production of \bar{p} 's from $\chi\text{--}\chi$ annihilation as a function of the kinetic energy is defined as

$$q_{\bar{p}}^{\text{susy}}(T_{\bar{p}}) \equiv \frac{dS(T_{\bar{p}})}{dT_{\bar{p}}} = \langle \sigma_{\text{ann}} v \rangle g(T_{\bar{p}}) \left(\frac{\rho_{\chi}(r, z)}{m_{\chi}} \right)^2. \quad (1)$$

Here $\langle \sigma_{\text{ann}} v \rangle$ denotes the average over the galactic velocity distribution function of neutralino pair annihilation cross section σ_{ann} multiplied by the relative velocity v of the annihilating particles, m_{χ} is the neutralino mass and $g(T_{\bar{p}})$ denotes the \bar{p} differential spectrum. Note the dependence on the square of the mass distribution function of neutralinos in the galactic halo, $\rho_{\chi}(r, z)$. For all the details of the computation of Eq.(1) and the main features of the Minimal Supersymmetric Standard Model (MSSM) – framework in which we calculated all the neutralino physical properties discussed in this talk – we refer to Sect. IIIB of Ref. ².

5 Comparison with BESS95 data

A recent analysis of the data collected by the BESS spectrometer during its 1995 flight ⁶ (BESS95) has provided a significant improvement in statistics in the kinetic-energy range $180 \text{ MeV} \leq T_{\bar{p}} \leq 1.4 \text{ GeV}$.

From a first look at Fig.2 it is apparent that the experimental data are rather consistent with the flux due to secondary \bar{p} 's. However, it is interesting to explore which would be the chances for a signal, due to relic neutralino annihilations, of showing up in the low-energy window ($T_{\bar{p}} \lesssim 1 \text{ GeV}$). This point is very challenging, especially in view of the interplay which might occur among low-energy measurements of cosmic-ray \bar{p} 's and other searches, of quite a different nature, for relic neutralinos in our Galaxy. Since the experimental flux seems to suggest a flatter behaviour, as compared to the one expected for secondaries, we try to explore how much room for neutralino \bar{p} 's would there be in the BESS95 data. As a quantitative criterion to select the relevant supersymmetric configurations, we choose to pick up only the configurations which meet the following requirements: i) they generate a total theoretical flux Φ^{th} which is at least at the level of the experimental value (within $1\text{--}\sigma$) in the first energy bin; ii) their $(\chi^2)_{\text{red}}$, in the best fit of the BESS95 data, is bounded by $(\chi^2)_{\text{red}} \leq 2.2$ (corresponding to 95% C. L. for 5 d.o.f.). On the other hand, supersymmetric configurations with a $(\chi^2)_{\text{red}} > 4$ have to be considered strongly disfavoured by BESS95 data (actually, they are excluded

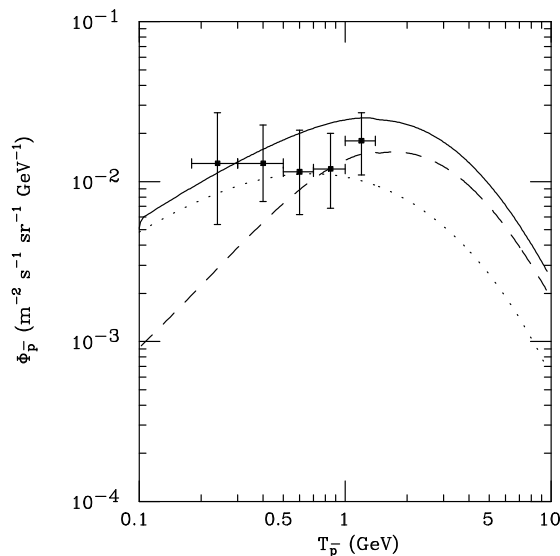


Figure 2: TOA antiproton fluxes versus the antiproton kinetic energy. The BESS95 data are shown by crosses. The dashed line denotes the median secondary flux, the dotted one denotes the primary flux due to neutralino annihilation in the halo for a neutralino configuration with $m_\chi = 62$ GeV, $P = 0.98$ and $\Omega_\chi h^2 = 0.11$. Solid line denotes the calculated total flux.

at 99.9 % C.L. See Ref.² for a detailed analyses of their properties). The selected configurations are shown in Fig.3, where m_χ is plotted in terms of the fractional amount of gaugino fields, $P = a_1^2 + a_2^2$, in the neutralino mass eigenstate. It can be seen that higgsino-like and mixed configurations are much stronger constrained in the neutralino mass range than the gaugino-like ones, because of the requirement on a rather high value of flux.

6 Comparison with the DAMA/NaI data on annual modulation effect

In Refs. ^{7,8} we showed that the indication of a possible annual modulation effect in WIMP direct search ^{9,10} are interpretable in terms of a relic neutralino which may make up the major part of dark matter in the Universe.

We recall that the DAMA/NaI data reported in Ref. ¹⁰ single out a very delimited 2- σ C.L. region in the plane $\xi\sigma_{\text{scalar}}^{(\text{nucleon})} - m_\chi$, where $\sigma_{\text{scalar}}^{(\text{nucleon})}$ is the WIMP-nucleon scalar elastic cross section and $\xi = \rho_\chi/\rho_l$ is the fractional

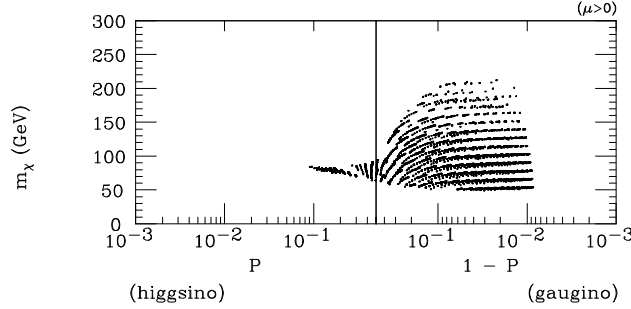


Figure 3: Scatter plots for selected (see text) configurations in the P - m_χ plane.

amount of local WIMP density ρ_χ with respect to the total local dark matter density ρ_l . In the analysis carried out in Ref.⁸, we considered all the supersymmetric configurations (set S) which turned out to be contained in the 2 - σ C.L. region of Ref.¹⁰, by accounting for the uncertainty in the value of ρ_l .

Fig.4 displays the scatter plots for TOA antiproton fluxes calculated at $T_{\bar{p}} = 0.24$ GeV, to conform to the energy range of the first bin of the BESS95 data ($0.175 \text{ GeV} \leq T_{\bar{p}} \leq 0.3 \text{ GeV}$). We find that, while most of the susy con-

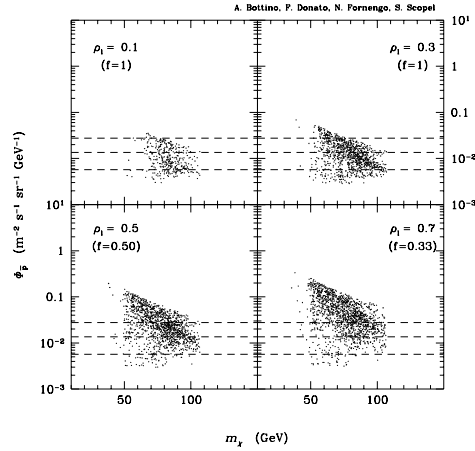


Figure 4: Scatter plots for the TOA antiproton fluxes calculated at $T_{\bar{p}} = 0.24$ GeV versus the neutralino mass, for the corresponding value of the local density ρ_l and flattening factor q . The dashed lines denote the central value and the 1 - σ band of the BESS95 data in the first energy bin.

figurations of the appropriate subset of S stay inside the experimental band for $\rho_l = 0.1, 0.3 \text{ GeV cm}^{-3}$, at higher values of ρ_l a large number of configurations provide \bar{p} fluxes in excess of the experimental results. This occurrence is

easily understood on the basis of the different dependence on ρ_l of the direct detection rate and of the \bar{p} flux, linear in the first case and quadratic in the second one. These results show the remarkable property that a number of the supersymmetric configurations singled out by the annual modulation data may indeed produce measurable effects in the low-energy part of the \bar{p} spectrum.

We stress that the joint use of the annual modulation data in direct detection and of the measurements of cosmic-ray antiprotons is extremely useful in pinning down a number of important properties of relic neutralinos and show the character of complementarity of these two classes of experimental searches for particle dark matter. This shows the great interest for the analyses now under way of new antiproton data, those collected by a recent balloon flight carried out by the BESS Collaboration¹¹ and those measured by the AMS experiment¹² during the June 1998 Shuttle flight.

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